Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean

James T. Kirby[1]
[1]Center for Applied Coastal Research, University of Delaware
Newark, DE 19716
Phone: (302) 831-2438 FAX: (302) 831-1228 E-mail: kirby@udel.edu

John S. Allen[2], Thomas G. Drake[4], Steve Elgar, Robert T. Guza[5], Kevin Haas[6], Daniel M. Hanes[7], Thomas H. C. Herbers[8], James M. Kaihatu[9], George Mellor[10], H. Tuba Ozkan-Haller[2], Ib A. Svendsen[1] and Edward B. Thornton[8]

[2]Oregon State University
[3]North Carolina State University
[4]Woods Hole Oceanographic Institution
[5]Scripps Institution of Oceanography
[6]Georgia Institute of Technology
[7]University of Florida
[8]Naval Postgraduate School
[9]Naval Research Laboratory, Stennis, MS
[10]Princeton University

Grant Number: N00014-99-1-1051

http://chinacat.coastal.udel.edu/~kirby/NOPP/

LONG-TERM GOALS

Our goal is to develop a comprehensive, verified community model that predicts nearshore hydrodynamics, sediment transport, and seabed morphology changes given offshore wave conditions and initial bathymetry.

OBJECTIVES

The basic scientific objective is to synthesize understanding of physical processes in the nearshore ocean by developing a model for

- waves and resulting radiation stresses and mass fluxes over evolving coastal bathymetry and currents
- wave-induced circulation
- sediment transport and morphological evolution

An additional objective is to test model components and the full community model with field observations.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Center for Applied Coastal Research,University of Delaware ,Newark,DE,19716**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
A National Oceanographic Partnership Program Award.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH AND WORK PLAN

Our approach is to develop a tightly-coupled system of individual model components, or modules. We are utilizing a framework where wave processes are distinguished from wave-averaged processes by means of a suitable time average. The resulting set of modules and their functions are:

- wave module - calculation of second- and third-moment wave properties, including frequency-directional spectra, radiation stresses, and wave skewness and asymmetry
- circulation module - calculation of wave-driven circulation and turbulence levels
- seabed module - calculation of local sediment fluxes and seabed changes resulting from flux divergences, and characterization of bed geometry

A model backbone will allow interaction and feedback between the individual modules and provide an interface to users. Candidate models to be used within each module are being investigated and tested. The model backbone will be constructed as an open architecture with a documented set of required inputs and outputs for each component, allowing users to provide alternative formulations for each module.

Wave modules based on energy balances and on frequency domain Boussinesq or mild-slope equations are being investigated. Phase resolving formulations will allow detailed time series of waves to be simulated, and stochastic approaches will allow waves over large nearshore regions to be modeled. Breaking wave dissipation will be included to model waves propagating across the surf zone.

Circulation will be modeled with SHORECIRC (SC) and the Princeton Ocean Model (POM). SC solves the short-wave averaged equations including the 3-dimensional structure of mean and infragravity band currents using forcing and mass flux calculations provided by the wave module. POM is a finite-difference approximation to the hydrostatic primitive equations with a free surface, and includes equations for continuity, momentum, temperature, and salinity.

The seabed module will model the local flux of sediment and the evolution of seafloor sedimentology and morphology. Field observations are being used to develop models for sediment flux driven by near-bottom velocities. Conservation of mass allows sediment flux calculations to be used to predict changes in large-scale nearshore bathymetry. The effects of bedforms such as ripples and megaripples will be incorporated into the modules.

Model components and the full community model will be tested by comparison with field observations of waves, currents, sea floor morphology and bathymetric evolution observed at a variety of field experiments.

WORK COMPLETED

A major goal of the project is to provide a community model for nearshore processes to the end-user community. This model is to be based on a backbone, presently referred to generically as the Master program, which handles the integration and control of individual model components. We have constructed a Master program which is now in its second major version, and have constructed a trial community model which uses the Master program to integrate the curvilinear-grid Shorecirc model, the monochromatic wave driver Ref/Dif 1, and a simple sediment transport model based on the

Bailard-Bowen-Bagnold formulation. A web-based distribution site has been established and will be upgraded to document available model components. The URL for the web site is http://chinacat.coastal.udel.edu/~kirby/programs/noppmodel/index.html. The site requires users to register, after which they have access to all site content.

The nearshore POM model and the unsteady wave driver of Kennedy and Kirby (2003) have also been successfully linked to the Master program, and work is underway to link a bulk energy flux model (Ozkan-Haller and Kirby, 1999). Efforts are being made to recruit external participants who may have an interest in testing the "openness" of the Master program interface by linking individual modules that have not been used to this point in the context of the project. Documentation of the interface between the Master program and each type of module is under development.

Spurred by progress in cross-shore transport predictions and the associated perception of need for directly modeled time histories of wave-induced velocities, a decision was made to provide the Boussinesq model FUNWAVE (Kennedy et al, 2000; Chen et al, 2000) as a combined wave and circulation module in the NOPP code. This configuration is achieved by regarding the Boussinesq model as a circulation code incorporating its own wave driver, eliminating the need for a separate wave driver to be specified.

Two boundary-layer formulations driven by instantantaneous, wave resolving free-stream horizontal velocities have been developed in the project and/or incorporated within existing project modules in order to model wave-driven cross-shore sediment transport. Results of this work are described below.

In order to specify incident wave and tidal current conditions for operational model use, the nearshore model needs to be linked effectively to either larger scale models or external data sources. Work aimed at achieving this linkage is ongoing both within the NOPP project and in related separate projects, including an ongoing Sea Grant project at Delaware. In this project, the nearshore version of POM has been successfully linked to a shelf-scale POM in order to examine the interaction between physical processes at the two scales. An example result is described below.

RESULTS

The development of a nearshore version of the Princeton Ocean Model (POM) makes possible the study of the interaction between the predominantly wave forced nearshore-surf zone and the wind forced innershelf. The first application of this capability is to the coastal flow offshore of Duck, North Carolina during the DUCK94 and CoOP projects. A high resolution inner model extending 10km off shore (Δx varying from 4m to 25m) is nested within a 100km domain (Δx varying from 25m to 250m). The initial application is two-dimensional (x,z) with along-shore homogeneity assumed.

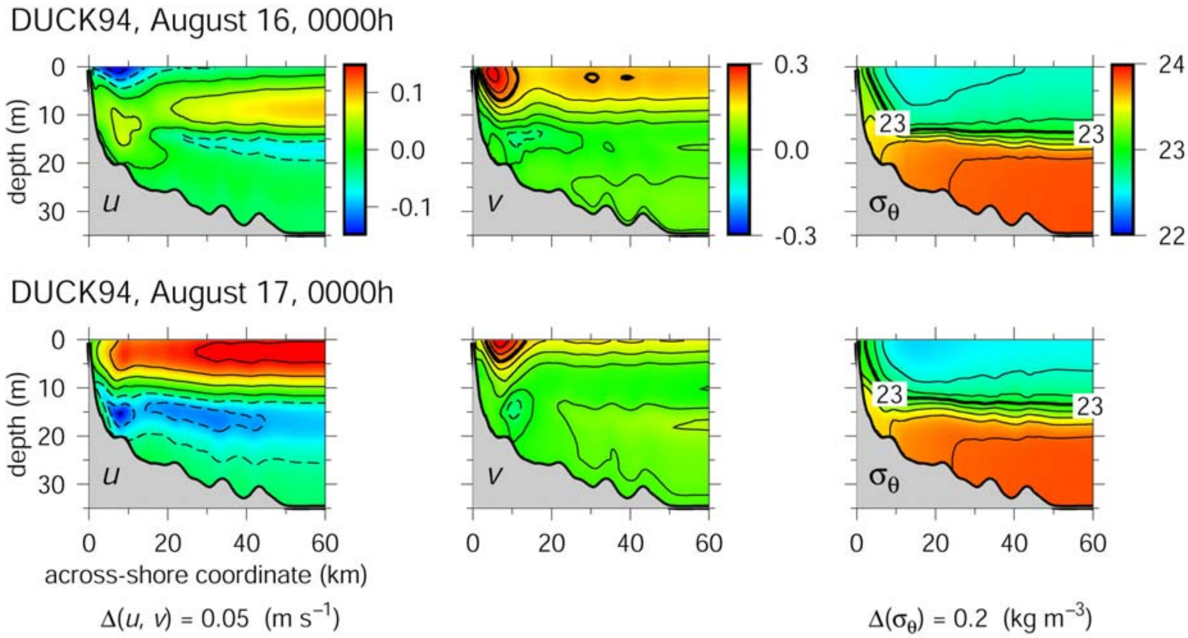

Figure 1: Large-scale POM Model Simulation of Velocities: Vertical Transects

The large scale model is forced by hourly winds and constant heat flux and is run for 15 days. Figure 1 shows the outer grid solution for two days preceding the inner grid run. The wind varies from weakly downwelling favorable to upwelling favorable during this period. The high resolution solution begins at 1100 Aug 17 and is a period of upwelling favorable winds and moderate waves from the southeast.

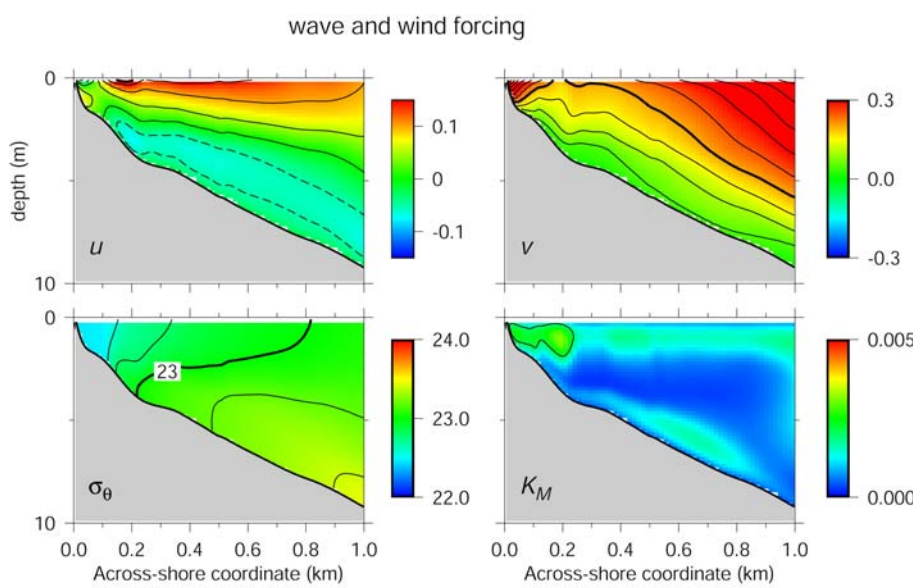

Figure 2: High Resolution Nearshore POM Simulation of Velocities: Vertical Transects

The inner, high resolution for Aug 17, 1700h (Figure 2) shows the effects of the wave forcing in the nearshore. With no bar and moderate waves, the wave forced circulation is restricted to about 100m from the coast. Off shore of about 400m the large alongshore currents are primarily wind forced. During this period stratification is important within a few hundred meters of the coast.

Recent work on cross-shore sediment transport under acretionary conditions has shown the importance of time history of near-bed velocity signal in determining cross-shore transport rates (Hoeffel and Elgar, 2003; Long and Kirby, 2003). These effects have often been described as "acceleration effects" but are more properly thought of as the signature of horizontal pressure gradient in the unsteady wave-induced flow. Hsu and Hanes (2004) have illustrated the effect of unsteady flow on near-bed shear stresses and resulting sheet flow. This and related work has spurred an effort within this project and elsewhere to look again at direct simulations of the mechanics of wave-induced bottom boundary layers. Henderson et al (2004) have developed a turbulent wave boundary layer model for suspended sediment transport, and have shown that the model is capable of providing successful simulations of shoreward bar motion when driven directly by measured field data from the DUCK '94 experiment.

IMPACT AND APPLICATIONS

The model system under development will provide a comprehensive predictive tool for nearshore processes, and will have a wide range of uses in the scientific community, as well as in DoD and civil planning and operations.

National Security

An ability to predict physical processes in the littoral environment is an important operational Navy need. The NOPP nearshore model is aimed at providing a detailed physical picture of a given, relocatable coastal environment over time scales of days or weeks.

Quality of Life

The nearshore model provides a detailed picture of the pattern of waves and wave-driven nearshore currents and resulting sediment transport. This capability can be used to enhance understanding of a range of coastal issues, including understanding of transport routes for pollutants, prediction of hazardous conditions for swimmers, and beach planform response to a sequence of wave conditions through time.

Science Education and Communication

The community model will be available as open source code, and will provide a comprehensive framework for educating students in coastal modeling as well as providing a documented system which can be extended at will to serve future students' particular needs or research aims.

TRANSITIONS

Science Education and Communication

The NOPP model has been developed with the input of a number of project supported students, and as thus already enhanced the education of a sizeable pool of students. The first beta distribution of a configured model is now available online and will serve as a basis for a worldwide pool of students learning about nearshore processes.

RELATED PROJECTS

The investigators in the NOPP project have a range of individual projects with closely related science and modeling objectives. The NOPP model development effort benefits these other ongoing studies by

increasing collaboration and exchange of results and data among the partners. The NOPP project allows results from individual investigations to be synthesized into a community-wide model for nearshore processes.

The University of Maryland Sea Grant project "Do oyster filtration and wave attenuation associated with oyster reefs and breakwaters improve seagrass habitat?" (Kirby, co-PI) is using the NOPP model framework and extending the Master program framework to incorporate a cohesive sediment capability and a water quality model.

The University of Delaware Sea Grant project "Coupling a Shelf Ocean Model and a Nearshore Community Model for Wave and Current Prediction at Tidal Inlets" (Shi and Kirby, PI's) is creating a framework for driving the nearshore model with data from shelf-scale model simulations of currents (ROMS) and waves (SWAN) using a distributed computing environment.

REFERENCES

Hoefel, F. and Elgar, S., 2003, “Wave-induced sediment transport and sandbar migration”, *Science*, **299**, 1885-1887.

Long, W. and Kirby, J. T., 2003, “Cross-shore sediment transport model based on the Boussinesq equations and an improved Bagnold formula”, *Proc. Coastal Sediments '03*, Clearwater Beach, May 17-22.

Özkan-Haller, H. T. and Kirby, J. T., “Nonlinear evolution of shear instabilities of the longshore current: A comparison of observations and computations”, *Journal of Geophysical Research*, 104, 25,953-25,984, 1999.

PUBLICATIONS

A full list of publications stemming from this project is updated continuously at http://chinacat.coastal.udel.edu/~kirby/NOPP/NOPPpubs.html.

Ardhuin, F., T. H. C. Herbers, and W. C. O'Reilly, 2001, “A hybrid Eulerian-Lagrangian model for spectral wave evolution with application to bottom friction on the continental shelf”, *J. Phys. Oceanogr.*, **31**, 1498-1516.

Ardhuin, F., and T. H. C. Herbers, 2002, “Bragg scattering of random surface gravity waves by irregular sea bed topography”, *J. Fluid Mech.*, **451**, 1-33.

Ardhuin, F., Drake, T. G. and Herbers, T. H. C., 2002, “Observations of wave-generated vortex ripples on the North Carolina continental shelf”, *J. Geophys. Res.*, **107(C10)**, 3143, doi:10.1029/2001JC000986.

Chang, Y.S. and D.M. Hanes, “Field observation and numerical investigation of the suspended sediment distribution over ripples seabeds”, submitted to *J. Geophys. Res.*, 2001.

Chen, Q., Kirby, J. T., Dalrymple, R. A., Shi, F. and Thornton, E. B., 2003, "Boussinesq modeling of longshore currents", *J. Geophys. Res.,* 108(C11), 3362, doi:10.1029/2002JC001308, 2003.

Chen, Q. and Svendsen, I. A., 2003, "Effects of boundary condition errors in nearshore circulation modeling", *Coastal Engineering,* **48**, 243-256.

Coco, G., Burnet, T., Werner, B. and Elgar, S., 2003, "Tests of self-organization in beach cusp formation", *J. Geophys. Res.,* **108**, 3101, doi:10.1029/2002JC001496.

Dohmen-Janssen, C. M. and D. M. Hanes, 2002, "Sheet flow dynamics under monochromatic nonbreaking waves", *J. Geophysical Research*, **107(C10)**, 3149, doi:10.1029/2001JC001045.

Elgar, S., 2001, "Coastal profile evolution at Duck, North Carolina: A cautionary note", *J. Geophys. Res.*, **106**, 4625-4627.

Elgar, S., Gallagher, E., and Guza, R. T., 2001, "Nearshore sand bar migration", *J. Geophys. Res.*, **106**, 11,623-11,627.

Elgar, S., B. Raubenheimer, and T.H. Herbers, 2003, "Bragg reflection of ocean waves from sandbars", *Geophysical Research Letters*, **30(1)**, 1016, doi:10.1029/2002GL016351.

Feddersen, F., and R.T. Guza, 2003, "Observations of nearshore circulation: Alongshore uniformity", *J. Geophys. Res.*, **108(C1)**, 3006, doi:10.1029/2001JC001293. and "Correction", *J. Geophys. Res.*, **108(C3)**, 3076, doi:10.1029/2001JC001801.

Feddersen, F., E. Gallagher, R.T. Guza, and S. Elgar, 2003, "The drag coefficient, bottom roughness, and wave-breaking in the nearshore", *Coastal Engrng.*, **48**, 189-195.

Feddersen, F., R.T. Guza, and S. Elgar, "Inverse modeling of one-dimensional setup and alongshore current in the nearshore", *J. Phys. Oceanog.*, submitted.

Haas, K. A. and I. A. Svendsen, 2002, "Laboratory measurements of the vertical structure of rip currents", *J. Geophys. Res.*, **107(C5)**, 10.1029/2001JC000911.

Haas, K. A., I. A. Svendsen, M. C. Haller and Q, Zhao, 2003, "Quasi-three-dimensional modelling of rip current systems", *J. Geophys. Res.* , **108(C7)**, 3217, doi:10.1029/2002JC001355.

Haas, K.A., and D.M. Hanes, 2003, "Process based modeling of total longshore sediment transport", *J. Coastal Research*, in press.

Hanes, D.M., V. Alymov, Y. Chang, and C.D. Jette, 2001, "Wave formed sand ripples at Duck, North Carolina", *J. Geophysical Research*, **106**, 22,575 - 22,592.

Henderson, S. M., J. S. Allen, and P. A. Newberger, 2003, "Nearshore sandbar migration predicted by an eddy-diffusive boundary layer model", *J. Geophys. Res.*, submitted.

Herbers, T. H. C., S. Elgar, N. A. Sarap, and R. T. Guza, 2002, "Nonlinear dispersion of surface gravity waves in shallow water", *J. Phys. Oceanogr.*, **32**, 1181-1193.

Herbers, T.H.C., M. Orzech, S. Elgar, and R. T. Guza, 2003, "Shoaling transformation of wave frequency-directional spectra", *J. Geophys. Res.*, **108(C1)**, 3013, doi:10.1029/2001JC001304.

Hsu, T.J., and D.M. Hanes, 2003, "The effect of flow acceleration on sediment transport", submitted to *J. Geophys. Res. - Oceans*.

Kaihatu, J M., 2001, "Improvement of a nonlinear parabolic dispersive wave model", *J. Waterway, Port, Coast. and Ocean Engrng.*, **127**, 113-121.

Kaihatu, J. M., 2003, "Frequency domain wave models in the nearshore and surfzones", in *Advances in Coastal Engineering*, V. C. Lakhan (ed), Elsevier.

Kennedy, A. B., Kirby, J. T. and Gobbi, M. F., 2002, "Simplified higher order Boussinesq equations. 1: Linear simplifications", *Coastal Engineering*, **44**, 205-229.

Kennedy, A. B. and Kirby, J. T., 2003, "An unsteady wave driver for narrowbanded waves: Modeling nearshore circulation driven by wave groups", *Coastal Engineering*, **48**, 257-275.

Kirby, J. T., 2003, "Boussinesq models and applications to nearshore wave propagation, surfzone processes and wave-induced currents", in *Advances in Coastal Engineering*, V. C. Lakhan (ed), Elsevier, 2003.

Martin, S.D., E.B. Thornton and T.P. Stanton, 2001, "Vortex ripple morphology using DUNE2D", submitted to *J. Geophys. Res.*

Mellor, G., 2002, "Oscillatory bottom boundary layers", *J. Phys. Oceanogr.*, **32**, 3075-.

Mellor, G., 2002, "The three-dimensional, current and surface wave equations", submitted to *J. Phys. Oceanogr.*

Noyes, T. J., R. T. Guza, S. Elgar, and T. H. C. Herbers, 2002, "Comparison of methods for estimating nearshore shear wave variance", *J. Atmos. Oceanic Tech.*, **19**, 136-143.

Noyes, T.J., R.T. Guza, S. Elgar, and T.H.C. Herbers, 2004, "Field observations of shear waves in the surf zone", *J. Geophys. Res.*, **109**, C01031, doi:10.1029/2002JC001761.

Puleo, J. A., O.Mouraneko, and D.M. Hanes, 2003, "1D wave bottom boundary layer comparison: specific eddy viscosity and turbulence closure models", submitted to *J Waterway, Port, Coast. Ocean Engrng.*

Reniers, A. J. H. M., Roelvink, J. A. and Thornton, E. B., 2004, "Morphodynamic modeling of an embayed beach under wave group forcing", *J. Geophys. Res.*,, **109**, C01030, doi:10.1029/2002JC001586.

Ruessink, G., J. Miles, F. Feddersen, R. T. Guza, and Steve Elgar, 2001, "Modeling the alongshore current on barred beaches", *J. Geophysical Research*, **106**, 22451-22463.

Sheremet, A., R. T. Guza, S. Elgar, and T. H. C. Herbers, 2002, "Observations of nearshore infragravity waves: Part 1 : Seaward and shoreward propagating components", *J. Geophys. Res.*, **107**, doi: 10.1029/2001JC000970.

Shi, F., Kirby, J. T., Dalrymple, R. A. and Chen, Q., 2003, "Wave simulations in Ponce de Leon Inlet using a Boussinesq model", *J. Waterway, Port, Coastal and Ocean Engineering*, **129**, 124-135.

Shi, F., Svendsen, I. A., Kirby, J. T. and Smith, J. M., 2003, "A curvilinear version of a quasi-3D nearshore circulation model", *Coastal Engineering*, **49**, 99-124.

Thorne, P. D. and D. M. Hanes, 2002, "A review of acoustic methods for the study of small scale sediment transport processes", *Continental Shelf Research*, **22**, 603-632.

Vincent, C.E. and D.M. Hanes, 2002, "The accumulation and decay of nearbed suspended sand concentration due to waves and wave groups", *Continental Shelf Research*, **22(14)**, 1987-2000.

Zhao, Q., Svendsen, I. A. and Haas, K., 2003, "Three-dimensional effects in shear waves", *J. Geophysical Research*, **108(C8)**, 3270, doi:10.1029/2002JC001306.